ACAS-Xu / Initial Self-Separation Flight Tests

Flight Test Report

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20 March 2015

Summary

Under various agreements between the FAA TCAS Program Office, General Atomics Aeronautical Systems Inc. (GA-ASI), and the National Aeronautics and Space Administration (NASA), the ACAS-Xu/Initial Self-Separation flight testing successfully demonstrated the following:

- ACAS Xu performing the collision avoidance (CA) function on the NASA “Ikhana” UAS against a manned intruder as well as the GA-ASI “Predator B” UAS also equipped with ACAS Xu; and,
- Self-Separation concept, which used displays and surveillance algorithms to inform UAS pilot maneuvers intended to anticipate and resolve conflicts before they become time critical, thus reducing the chance that a threat would progress to a collision avoidance alert in the first place.

Over the period starting 17 November 2014 to 19 December 2014, a total of six ACAS-Xu CA flights were flown along with three Self-Separation flights within R-2515 at Edwards AFB. A total of 170 flight test encounters were flown with over 50 hours of Collision Avoidance or Self Separation data collection utilizing the Ikhana aircraft as ownship and either the GA-ASI UAS, FAA Convair, Honeywell King Air, or the NASA T-34 as the intruder.

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1 Description

The purpose of this flight test report is to document and report the details of the ACAS Xu/Self-Separation flight test series performed at Edwards AFB from November to December of 2014. Included in this document are details about participating aircraft, aircrew, mission crew, system configurations, flight data, flight execution, flight summary, test results, and lessons learned.

2 Flight Test Period

The flight test period spanned from 17 November 2014 to 19 December 2014. The flight days are detailed in Table 1, below.

Table 1. ACAS-Xu/Initial Self-Separation Flight Dates

Flight Number	Flight Date	Objective
1	17 November 2014	ACAS-Xu
2	18 November 2014	ACAS-Xu
3	20 November 2014	ACAS-Xu
4	21 November 2014	ACAS-Xu
5	9 December 2014	ACAS-Xu
6	10 December 2014	ACAS-Xu
7	15 December 2014	Self-Separation
8	18 December 2014	Self-Separation
9	19 December 2014	Self-Separation

3 Flight Crew and Mission Team

The NASA Ikhana UAS served as the primary ownship for the entire flight test series (ACAS-Xu and SS). All flight test encounter setups included a single ownship vs. a single intruder; the intruder role was supported by multiple aircraft due to availability and crew rest considerations. The aircraft and flight crew required to complete the test series are identified in Table 2.

Table 2. ACAS-Xu/SS Aircraft and Flight Crew

Aircraft	Role	Position	Flight Crew
NASA 870 Ikhana	ACAS-Xu and SS Ownship	NASA Pilots	Howe, Posada, Less
		Air National Guard Pilots	Reiss, Devereau
		NASA Mission Director	Buoni, Howell
N39 Convair	ACAS-Xu Intruder	FAA Pilots	Van Hoy, Geyser
		FAA FTEs	Carino, Fehr, Bansback
N3GC C90	ACAS-Xu and SS Intruder	Honeywell Pilots	Dubbury, Nyberg
		Honeywell FTEs	Singh, Dougherty
N308HK MQ-9	ACAS-Xu Intruder	GA-ASI Pilots	Dunfee, Adams, Busch, Endert
		GA-ASI Mission Director	Jeremy, Johnston
NASA 865 T-34C	ACAS-Xu and SS Intruder; Calibration Flights	Pilots	Dana, Miller

Along with the aircraft and flight crew assets, a mission team was utilized to manage the overall test effort. The test conductor was responsible for overall mission success and the coordination of all test assets. The test director provided support to the test conductor by performing all back channel and engineering channel coordination. For the ACAS-Xu phase, MIT Lincoln Labs was given NASA approval to perform the role of the test conductor. NASA provided the test conductor role for the Self-Separation phase. Table 3, below, provides a listing of the mission team.

Table 3. Mission Team

Mission Team	
NASA Test Conductor	Marston (SS)
MIT Lincoln Labs Test Conductors	Maki (CA), Teller (CA)
NASA Test Directors	Marston (CA), Baca (SS)

4 System Configuration

All aircraft that participated in this flight test were equipped with navigation systems that use Global Positioning System (GPS) derived position. All manned intruder aircraft were equipped with TCAS, and the FAA Convair, HW C90 and GA-ASI MQ-9 were equipped with TCAS II version 7.1. For the purpose of situational awareness on the ground, interoperability demonstration, and data collection, all aircraft were equipped with ADS-B.

As stated previously, the Ikhana UAS supported the flight series as the ownship. As ownship, the ACAS Xu algorithm was hosted on a Ballard AB3125/PMC05 Rugged

Computer (aka Ballard Box), which was integrated onto Ikhana. ACAS Xu computed the estimated states of threat aircraft, then selected an action according to a look up table to determine a resolution advisory (RA) (if needed). Detecting airborne vehicles not equipped with transponders (i.e., non-cooperative) is key to safely integrating UAS into the NAS. The GA-ASI Air-To-Air-Radar (ATAR) was integrated into Ikhana for this flight test to demonstrate this component of SAA.

GA-ASI provided a "Capital" Predator B (MQ-9) that supported two UAS vs UAS flights. This Predator B was equipped similarly to Ikhana but was only used to support the test as an unmanned intruder threat aircraft.

Further, the Ikhana UAS hosted, in the GCS, three unique displays and algorithms used during the flight test for the purpose of testing and evaluating sense and avoid concepts. During the collision avoidance portion of the flight test, the CPDS display served as the primary display for ACAS Xu traffic advisories (TA) with conflict resolution mode turned off. Self Separation Stratway+ and Vigilant Spirit/Autoresolver displays were also running in the background (aft section of the Ikhana GCS) for data collection purposes only, but were not used as a primary display during CA testing. During the self-separation portion of the flight test, the same CPDS display was one of three different systems used as a display under test. Self-Separation maneuvers were conducted with the pilot-in-the-loop (i.e., actively controlling the aircraft) conducting maneuvers according to one of the following self-separation displays: CPDS, Stratway+, and Vigilant Spirit/Autoresolver.

A high level summary of the equipage installed on each aircraft is found in Table 4.

Table 4. Aircraft Equipage

Tail Number	Equipment
NASA 870	ACAS Xu avionics: ADS-B, ATAR, TCAS II; GPS, HUD
FAA N39	ADS-B, TCAS II, GPS
HW N3GC	ADS-B, TCAS II, GPS, TCAS Recorder
GA-ASI N308HK	ADS-B, TCAS II, GPS, HUD
NASA 865	TCAS I, GPS

5 Flight Data

5.1 Operating Area

The operating area for all flight test occurred in the Restricted Airspace, R-2515, located at the Edwards AFB, along with the Buckhorn MOA (used by manned intruders only), with operations scheduled and coordinated through the Air Force Test Center (AFTC). Specific airspace scheduled each day during these flight tests included the Four

Corners Area, Mercury Spin Area, overflight of the PIRA East/West ranges, and the Buckhorn MOA. These areas within R-2515 are depicted within the yellow shaded area shown in the breakout box found in Figure 1.

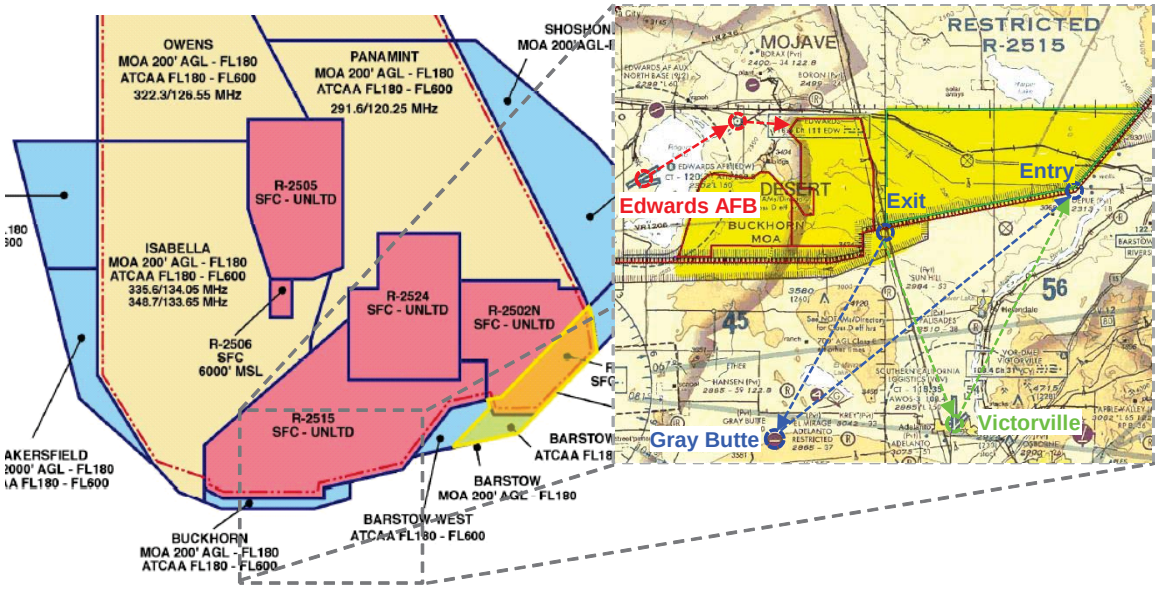


Figure 1. ACAS-Xu/SS Flight Test Area

5.2 Weather

Two scheduled flights were impacted by adverse weather (no-go item) the morning of flight which caused one cancelation and one multiple hour delay. One flight was rescheduled due to a day prior unfavorable forecast. Visual Meteorological Conditions (VMC), clear of clouds, with lowest ceiling exceeding 1,000 feet above the designated altitude block (between 7,000 feet and 20,000 feet MSL) and visibility exceeding 3 statute miles were required (mission rule). Any other potentially prohibiting flight conditions such as wind, turbulence, and/or precipitation that exceed established criteria for launch or recovery canceled or delayed tests until conditions were within tolerance. Any other conditions that interfered with successful flight test outcomes were taken under consideration by the team. Before each scheduled flight, the test team made a final “go/no-go” decision based upon the current and forecasted weather or any other last minute changes to operational restrictions.

5.3 Aircraft Status

Aircraft Status was reported on at each flight’s day prior (T-1) briefing and reviewed again during each morning crew brief to determine whether changes to that status existed. Participating aircraft were required to perform a pre-flight checkout prior to taking flight. All NASA aircraft staged/departed to the test area from Armstrong Flight Research Center (KEDW). The FAAs Convair team staged from McCarran Airport in

Las Vegas, NV. The Honeywell King Air (C90) staged from Van Nuys Airport, CA. GA-ASI's Capital Predator B staged from their home station at Gray Butte, CA. Figure 2 depicts the staging location for each participating aircraft.

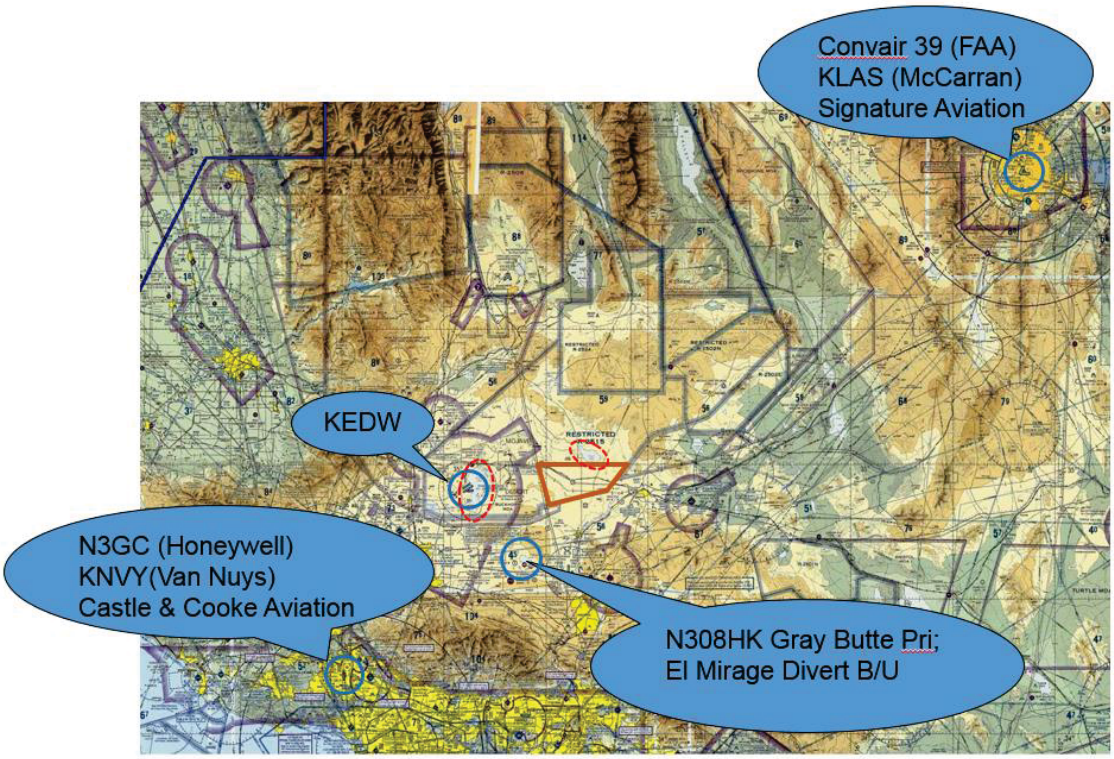


Figure 2. Aircraft Staging

5.4 Mission Information

Given the complexity of the team makeup with regard to number of participating aircraft, multiple base locations, and multiple stakeholders, executing the ACAS-Xu/SS flights required a significant amount of coordination. A notional flight schedule was developed after months of planning; however, real-time circumstances often drove the need to alter the baseline schedule.

As a pre-requisite to executing on a scheduled flight, the test conductor was required to conduct a team T-1 (day prior) briefing. The T-1 briefing covered, in detail, the following aspects related to the upcoming flight:

- Roll Call
- Mission Summary
- Mission Timeline
- Weather / NOTAMs
- UAS Status

- Mission Information
- GCS Status
- Airspace / Airfield
- Support Assets
- Contingencies
- Additional Briefs
- Flight Card Review

A flight could be delayed or postponed based on information discussed during the T-1 briefing. All participating team members were required to participate in the briefing either in-person or by telecom.

Most ACAS-Xu/SS flights started at 0600 (local) Pacific Time. Subsequently, any morning crew briefings were held at 0400 the morning of the scheduled flight. The morning crew briefings covered the same details as the T-1 briefing but at a higher level. The intent was for this briefing to be about 15 minutes in length. Changes made to the test card order and weather updates were covered in greater detail. A final go/no-go decision was made at this crew briefing. After the brief, the team was released to prepare for the flight.

In general, flights were planned for approximately 3.5 - 4 hours long (actual sortie durations were 3.9 to 5.8 hours in length). A flight debrief was mandatory in order to discuss lessons learned, review test objectives for the next flight, and perform a post-flight test card review and high level data analysis.

5.5 Training and Qualifications

All visiting flight crew team members were required to participate in local area familiarization briefing, and conduct a local area familiarization flight. In addition, all flight crew and mission team members were required to have obtained current Crew Resource Management (CRM) training. The test conductor required formal approval from the NASA Armstrong Director of Flight Operations in order to serve in that capacity. The requirements for the ACAS-Xu/SS test conductor were derived from NASA Armstrong DCP-O-003, Mission Control Procedure. The requirements were tailored from the mission controller section. Due to time constraints to obtain these approvals, and that two of the candidate test conductors were not physically located at Armstrong to participate in most of the OJT aspect of the training requirements, experience in lieu of training was submitted and subsequently approved.

6 Flight Execution

The ACAS-Xu/SS flights were split into two distinct phases: Collision Avoidance flights, and Self-Separation flights. The sections below describe the flight execution activities related to each phase.

6.1 Collision Avoidance

The CA scenarios tested ACAS Xu threat resolution logic using two different trackers and multiple surveillance sources. Software and surveillance performance were evaluated and tested for a more complete understanding of the effects on the performance of the ACAS Xu prototype threat resolution logic.

The collision avoidance scenarios began at a point that was approximately 2 minutes from the Closest Point of Approach (CPA), with a RA alert from ACAS Xu expected prior to CPA. The scenarios were planned such that the ACAS-Xu algorithm was expected to generate an alert while the risk of a Near-Mid-Air-Collision (NMAC) was mitigated by a horizontal offset of no less than 0.5 NM and a vertical offset of no less than 200 feet.

The following describes the Collision Avoidance encounter-types and geometries:

- Encounter types/geometries:
    - Head On – Intruder approached ownship in head-on geometry with horizontal and vertical offsets.
    - Overtake – Intruder approached ownship from behind (at higher groundspeed) with horizontal and vertical offsets.
    - Crossing – Intruder approached ownship from an angle as specified; timing and geometries are planned to maintained horizontal and vertical offsets.

Table 5 outlines the basic requirements for execution, safety mitigation, and prioritization for planned ACAS Xu Collision Avoidance scenarios. These scenarios were the basis of establishing a flight schedule and building flight test cards (Figure 3 and Figure 4 depict example ACAS Xu CA test cards).

Table 5. Collision Avoidance Scenario Table

Vertical Profile	Scenario Designation	Flight Test Software Configuration Requirements					CPA Time Tolerance (3σ) Requirement	P(NMAC) Given CPA Time Tolerance	Visual Acquisition Required (critical)	Expected Alert Time Before CPA	Automatic Response to RA	Allowed Resolution Advisories to follow	Planned Minimum Vertical Seperation	Calibration Leg Required	Calibration Discrepencies Allowed	Ikhana Lost Link Mission	Pred B Lost Link Mission
		Software Configuration One(1)	Software Configurationn Two (2)	Software Configuration Three (3)	Software Configuration Four (4)	GA-ASI Pred B Requirements											
10 Series Scenarios 500 Foot Level	SCENARIO X11	Not Required	Not Required	No Fly	No Fly	Not Required	+/- 16 Seconds	< 1.3×10^{-9} Regardless of Timing	NO	Not Applicable	NO	Descend Sense only: "Descend", or "Do not climb"	500 ft	NO	N/A	NASA EAST	GA_M1
	SCENARIO X12	Required	Required	No Fly	No Fly	Required	Not Applicable										GA_M2
	SCENARIO X13	Required	Not Required	No Fly	No Fly	Required	+/- 16 Seconds										
	SCENARIO X14	Required	Not Required	No Fly	No Fly	Required	+/- 13 Seconds										
	SCENARIO X15	Required	Not Required	No Fly	No Fly	Not Required	+/- 10 Seconds										
	SCENARIO X16	Required	Not Required	No Fly	No Fly	Not Required	+/- 8 Seconds					Climb Sense only: "Climb", or "Do not descend"				NASA WEST	GA_M3
	SCENARIO X17	Required	Not Required	No Fly	No Fly	Not Required	+/- 6 Seconds										
	SCENARIO X18	Required	Not Required	No Fly	No Fly	Not Required	+/- 5 Seconds										GA_M4
	SCENARIO X19	Required	Required	No Fly	No Fly	No Fly	Not Applicable										N/A
20 Series Scenarios 200 Foot Level	SCENARIO X21	Not Required	Not Required	No Fly	No Fly	Not Required	+/- 16 Seconds	1.8×10^{-7}	YES	-38 Sec	YES	Corrective: "Descend"	200 ft	YES	Less than 100ft pre-corrected altitude discrepency, less than 0.1 NM for navigation	NASA EAST	GA_M1
	SCENARIO X22	Required	Required	No Fly	No Fly	Required	Not Applicable	$< 1.0 \times 10^{-9}$									GA_M2
	SCENARIO X23	Required	Not Required	No Fly	No Fly	Required	+/- 16 Seconds	1.8×10^{-7}									
	SCENARIO X24	Required	Not Required	No Fly	No Fly	Required	+/- 13 Seconds	5.5×10^{-6}									
	SCENARIO X25	Not Required	Not Required	No Fly	No Fly	Not Required	+/- 10 Seconds	3.6×10^{-5}									
	SCENARIO X26	Not Required	Not Required	No Fly	No Fly	No Fly	+/- 8 Seconds	7.5×10^{-5}				Corrective: "Climb"				NASA WEST	N/A
	SCENARIO X27	Not Required	Not Required	No Fly	No Fly	No Fly	+/- 6 Seconds	1.2×10^{-4}									
	SCENARIO X28	Not Required	Not Required	No Fly	No Fly	No Fly	+/- 5 Seconds	2.6×10^{-4}									
	SCENARIO X29	Required	Required	No Fly	No Fly	No Fly	Not Applicable	$< 1.0 \times 10^{-9}$		-48 Sec							
30 Series Scenarios 500 Foot Blunders	SCENARIO X31	Not Required	Not Required	No Fly	No Fly	Not Required	+/- 16 Seconds	1.8×10^{-7}	YES	-22 Sec	YES	Corrective: "Descend"	200 ft	YES	Less than 100ft pre-corrected altitude discrepency, less than 0.1 NM for navigation	NASA EAST	GA_M1
	SCENARIO X32	Required	Required	No Fly	No Fly	Required	Not Applicable	$< 1.0 \times 10^{-9}$									GA_M2
	SCENARIO X33	Required	Required	No Fly	No Fly	Required	+/- 16 Seconds	1.8×10^{-7}									
	SCENARIO X34	Required	Required	No Fly	No Fly	Required	+/- 13 Seconds	5.5×10^{-6}									
	SCENARIO X35	Not Required	Not Required	No Fly	No Fly	Not Required	+/- 10 Seconds	3.6×10^{-5}									
	SCENARIO X36	Not Required	Not Required	No Fly	No Fly	No Fly	+/- 8 Seconds	7.5×10^{-5}				Corrective: "Climb"				NASA WEST	N/A
	SCENARIO X37	Not Required	Not Required	No Fly	No Fly	No Fly	+/- 6 Seconds	1.2×10^{-4}									
	SCENARIO X38	Not Required	Not Required	No Fly	No Fly	No Fly	+/- 5 Seconds	2.6×10^{-4}									
	SCENARIO X39	Required	Required	No Fly	No Fly	No Fly	Not Applicable	$< 1.0 \times 10^{-9}$		-15 Sec							
40 Series Scenarios 1000 Foot Blunders	SCENARIO X41	Not Required	Not Required	No Fly	No Fly	Not Required	+/- 16 Seconds	3.9×10^{-9}	YES	-30 Sec	YES	Corrective: "Descend"	300 ft	YES	Less than 100ft pre-corrected altitude discrepency, less than 0.1 NM for navigation	NASA EAST	GA_M1
	SCENARIO X42	Required	Required	No Fly	No Fly	Required	Not Applicable	$< 1.0 \times 10^{-9}$									GA_M2
	SCENARIO X43	Required	Required	No Fly	No Fly	Required	+/- 16 Seconds	3.9×10^{-9}									
	SCENARIO X44	Required	Required	No Fly	No Fly	Required	+/- 13 Seconds	1.2×10^{-7}									
	SCENARIO X45	Not Required	Not Required	No Fly	No Fly	Not Required	+/- 10 Seconds	7.6×10^{-7}									
	SCENARIO X46	Not Required	Not Required	No Fly	No Fly	No Fly	+/- 8 Seconds	1.6×10^{-6}				Corrective: "Climb"				NASA WEST	N/A
	SCENARIO X47	Not Required	Not Required	No Fly	No Fly	No Fly	+/- 6 Seconds	2.6×10^{-6}									
	SCENARIO X48	Not Required	Not Required	No Fly	No Fly	No Fly	+/- 5 Seconds	5.6×10^{-6}		-28 Sec							
	SCENARIO X49	Required	Required	No Fly	No Fly	No Fly	Not Applicable	$< 1.0 \times 10^{-9}$		-10 Sec							
50 Series Non-coop	SCENARIO X51	No Fly	No Fly	Required	Required	No Fly	+/- 16 Seconds	$< 1.0 \times 10^{-9}$ Regardless of Timing	NO	Not Applicable	NO	"Turn Right"	2000 ft	NO	N/A	NASA EAST	N/A
	SCENARIO X52	No Fly	No Fly	Required	Required	No Fly	Not Applicable				YES	"Turn Left"					
	SCENARIOX 53	No Fly	No Fly	Required	Required	No Fly	+/- 16 Seconds				NO						
	SCENARIO X54	No Fly	No Fly	Required	Required	No Fly	+/- 13 Seconds										
	SCENARIO X55	No Fly	No Fly	Required	Required	No Fly	+/- 10 Seconds										
	Scenarios planned to Fly:	36	36	5	5	23											
	Scenarios Required:	20	12	5	5	12											

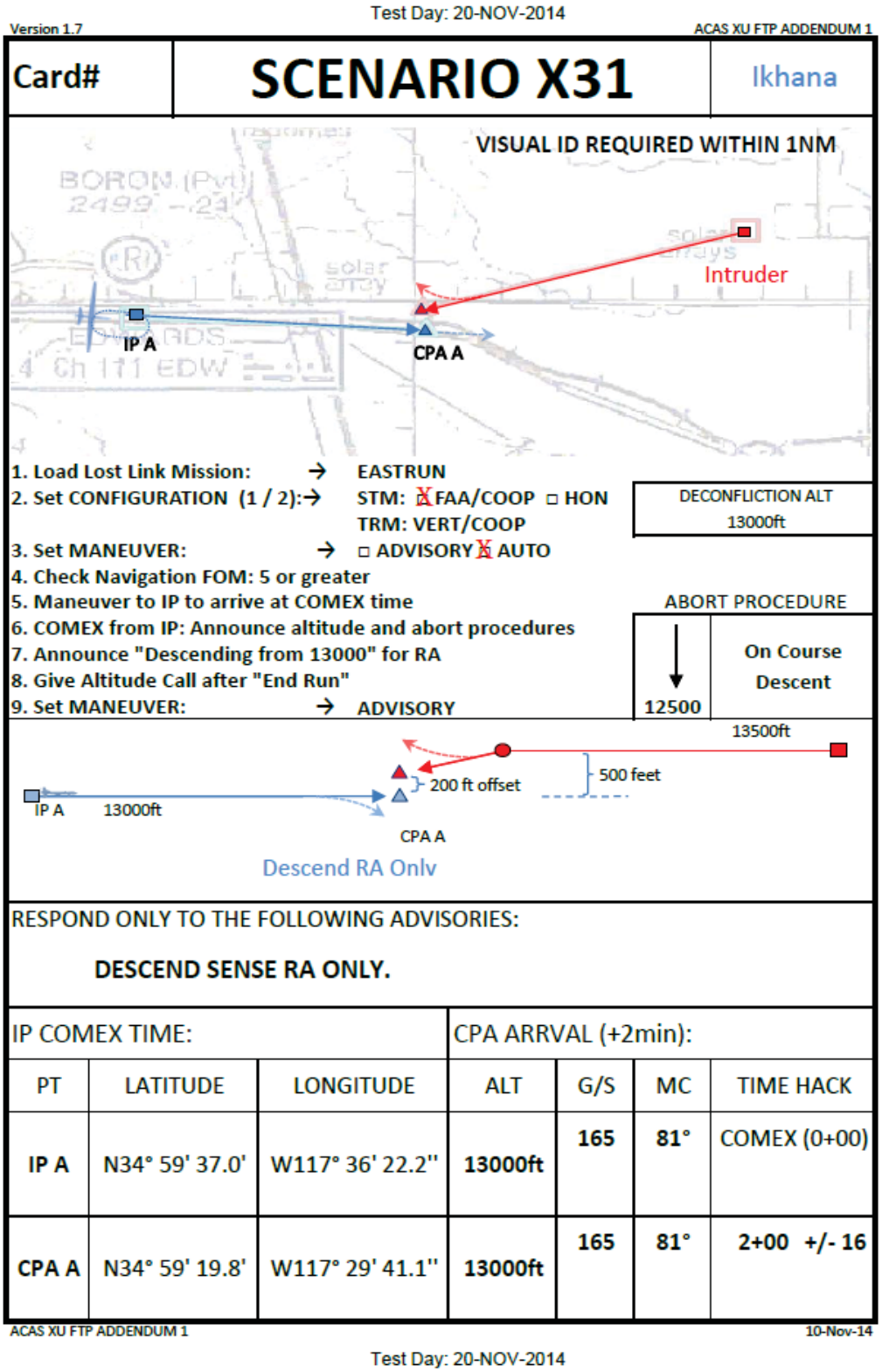
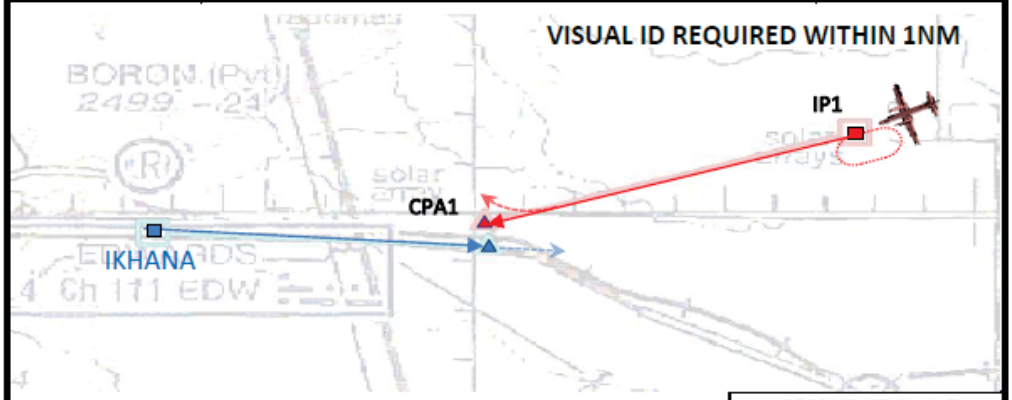


Figure 3. Collision Avoidance Ikhana Example Test Card

Test Day: 20-NOV-2014

Version 1.7 ACAS XU FTP ADDENDUM 1

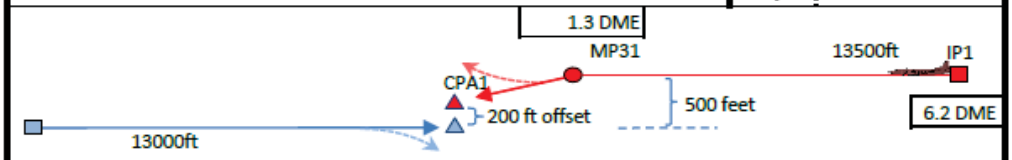
Card#	SCENARIO X31	Intruder



DECONFLICTION ALT
14000ft

1. Take initial altitude AFTER Ikhana calls 13000
2. Check Navigation: → Mode: GPS Only → FOM/Q: ____
3. Check TCAS: □ TA/RA □ TA ONLY
4. Maneuver to IP to arrive at COMEX time
5. COMEX from IP: Announce altitude and abort procedures
6. After "End Run": Proceed to IP ___ and hold

ABORT PROCEDURE
If Visual:
Abort to Remain well clear
Otherwise:
14000 ↑ Turn Right Heading 300°



Do Not Follow TCAS RA (exception for non-participating traffic)

IP COMEX TIME:			CPA ARRVAL (+2min):			
PT	LATITUDE	LONGITUDE	DME / ALT	G/S	MC	TIME HACK
IP1	N35° 01.62'	W117° 22.58'	**6.2** / **13500ft**	**185**	**241°**	COMEX (0+00)
MP31	N35° 00.21'	W117° 28.21'	**1.3** / **-700fpm**			**1+34**
CPA1	N34° 59.82'	W117° 29.76'	**0.0** / **13200ft**	**185**	**241°**	**2+00 +/- 16**

ACAS XU FTP ADDENDUM 1 10-Nov-14

Test Day: 20-NOV-2014

Figure 4. Collision Avoidance Intruder Example Test Card.

6.2 Self-Separation

The objective of the Self-Separation scenarios was to demonstrate detection and tracking of aircraft from ADS-B, Active Surveillance (TCAS) and the GA-ASI DRR while using self-separation guidance from each of the displays described in section 4.

Each scenario began with each aircraft starting the run at a greater distance prior to the CPA than during the Collision Avoidance flights. This increased separation was required to prevent the DRR from detecting the Intruder at the start of the scenario but still within the TCAS and ADS-B detection range. The Intruder CPA was a predefined position with offsets of 1.5 NM, 1.0 NM, and 0.5 NM, and 0 NM to the ownship CPA. All scenarios were flown with at least 4,000 feet of vertical separation between Ikhana and the intruder(s). The engineering mode for each display, and corresponding self-separation algorithms, were set to adjust vertical offset to simulate aircraft at equivalent altitudes.

The following describes the Self-Separation encounter-types and geometries:

- Encounter types/geometries:
    - Head On – Intruder approached ownship in head-on geometry, though with horizontal and vertical offsets. A zig-zag scenario is included in this group to support DRR testing.
    - Overtake – Intruder approached ownship from behind (at higher groundspeed) with horizontal and vertical offsets as indicated.
    - Crossing – Intruder approached ownship from an angle as specified; timing and geometries are planned to maintained horizontal and vertical offsets.

Table 6 outlines the basic requirements for execution, safety mitigation, and prioritization for planned Self-Separation scenarios. These scenarios were the basis of establishing a flight schedule and building flight test cards (Figure 5 and Figure 6 depict example ACAS Xu SS test cards).

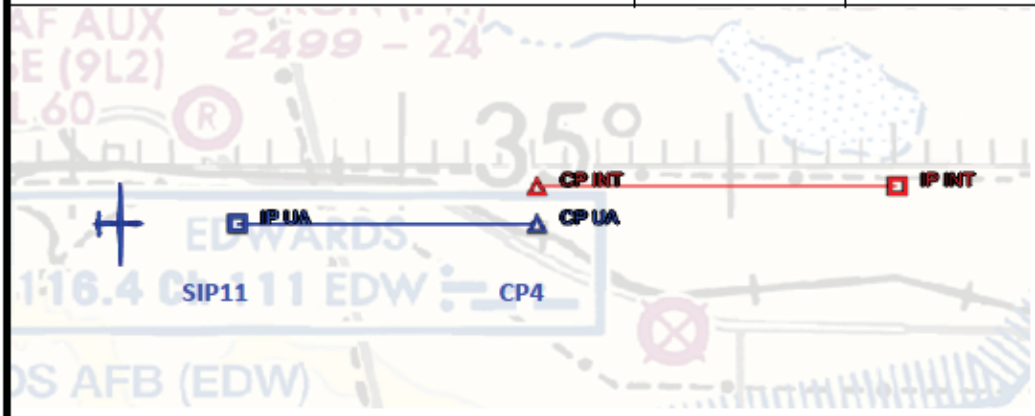
Table 6. Self-Separation Scenario Table

		CPA Distance	CPA Placement	Initial Offset	Ownship Altitide	Intruder Entry Alt	Intruder CPA Alt	GS OWN	GS INT	VS / AutoResolver	Stratway+	CPDS
Head-On	SCENARIO S11	1.5	BEHIND	1.8	12000	16000	16000	150	180			Required
	SCENARIO S12	1.0	BEHIND	1.8	12000	16000	16000	150	180		Required	
	SCENARIO S13	0.5	BEHIND	1.8	12000	16000	16000	150	180	Required	Required	Required
	SCENARIO S14	0.0	MERGE	1.8	12000	16000	16000	150	180		Required	
	SCENARIO S15	0.5	FRONT	1.8	12000	16000	16000	150	180	Required		
	SCENARIO S16	1.0	FRONT	1.8	12000	16000	16000	150	180			
	SCENARIO S17	1.5	FRONT	1.8	12000	16000	16000	150	180			
45° Crossing Left-to-Right	SCENARIO S21-a	1.5	BEHIND	2.5	12000	16000	16000	150	180			
	SCENARIO S22-a	1.0	BEHIND	2.5	12000	16000	16000	150	180			
	SCENARIO S23-a	0.5	BEHIND	2.5	12000	16000	16000	150	180			
	SCENARIO S24-a	0.0	MERGE	2.5	12000	16000	16000	150	180		Required	
	SCENARIO S25-a	0.5	FRONT	2.5	12000	16000	16000	150	180		Required	
	SCENARIO S26-a	1.0	FRONT	2.5	12000	16000	16000	150	180		Required	
	SCENARIO S27-a	1.5	FRONT	2.5	12000	16000	16000	150	180			
	SCENARIO S21-b	1.5	BEHIND	2.5	12000	16000	16000	150	180			
	SCENARIO S22-b	1.0	BEHIND	2.5	12000	16000	16000	150	180	Required		
	SCENARIO S23-b	0.5	BEHIND	2.5	12000	16000	16000	150	180	Required		
	SCENARIO S24-b	0.0	MERGE	2.5	12000	16000	16000	150	180		Required	
	SCENARIO S25-b	0.5	FRONT	2.5	12000	16000	16000	150	180	Required		
	SCENARIO S26-b	1.0	FRONT	2.5	12000	16000	16000	150	180	Required		
	SCENARIO S27-b	1.5	FRONT	2.5	12000	16000	16000	150	180			
	SCENARIO S21-c	1.5	BEHIND	2.5	12000	16000	16000	150	180			Required
	SCENARIO S22-c	1.0	BEHIND	2.5	12000	16000	16000	150	180			
	SCENARIO S23-c	0.5	BEHIND	2.5	12000	16000	16000	150	180	Required		
	SCENARIO S24-c	0.0	MERGE	2.5	12000	16000	16000	150	180		Required	
	SCENARIO S25-c	0.5	FRONT	2.5	12000	16000	16000	150	180	Required		Required
	SCENARIO S26-c	1.0	FRONT	2.5	12000	16000	16000	150	180			
	SCENARIO S27-c	1.5	FRONT	2.5	12000	16000	16000	150	180			Required(2 Runs)
90° Crossing Left-to-Right	SCENARIO S31-a	1.5	BEHIND	2.5	12000	16000	16000	150	180			
	SCENARIO S32-a	1.0	BEHIND	2.5	12000	16000	16000	150	180			
	SCENARIO S33-a	0.5	BEHIND	2.5	12000	16000	16000	150	180			
	SCENARIO S34-a	0.0	MERGE	2.5	12000	16000	16000	150	180		Required	
	SCENARIO S35-a	0.5	FRONT	2.5	12000	16000	16000	150	180		Required	
	SCENARIO S36-a	1.0	FRONT	2.5	12000	16000	16000	150	180		Required	
	SCENARIO S37-a	1.5	FRONT	2.5	12000	16000	16000	150	180			
	SCENARIO S31-b	1.5	BEHIND	2.5	12000	16000	16000	150	180			
	SCENARIO S32-b	1.0	BEHIND	2.5	12000	16000	16000	150	180	Required		
	SCENARIO S33-b	0.5	BEHIND	2.5	12000	16000	16000	150	180	Required		
	SCENARIO S34-b	0.0	MERGE	2.5	12000	16000	16000	150	180		Required	
	SCENARIO S35-b	0.5	FRONT	2.5	12000	16000	16000	150	180	Required		
	SCENARIO S36-b	1.0	FRONT	2.5	12000	16000	16000	150	180	Required		
	SCENARIO S37-b	1.5	FRONT	2.5	12000	16000	16000	150	180			
	SCENARIO S31-c	1.5	BEHIND	2.5	12000	16000	16000	150	180			Required
	SCENARIO S32-c	1.0	BEHIND	2.5	12000	16000	16000	150	180			
	SCENARIO S33-c	0.5	BEHIND	2.5	12000	16000	16000	150	180	Required		
	SCENARIO S34-c	0.0	MERGE	2.5	12000	16000	16000	150	180		Required	
	SCENARIO S35-c	0.5	FRONT	2.5	12000	16000	16000	150	180	Required		Required
	SCENARIO S36-c	1.0	FRONT	2.5	12000	16000	16000	150	180			
	SCENARIO S37-c	1.5	FRONT	2.5	12000	16000	16000	150	180			Required(2 Runs)
Overtaking	SCENARIO S41	1.5	BEHIND	2.5	12000	16000	16000	130	180			
	SCENARIO S42	1.0	BEHIND	2.5	12000	16000	16000	130	180			
	SCENARIO S43	0.5	BEHIND	2.5	12000	16000	16000	130	180			
	SCENARIO S44	0.0	MERGE	2.5	12000	16000	16000	130	180	Required		
	SCENARIO S45	0.5	FRONT	2.5	12000	16000	16000	130	180			
	SCENARIO S46	1.0	FRONT	2.5	12000	16000	16000	130	180			
	SCENARIO S47	1.5	FRONT	2.5	12000	16000	16000	130	180			
30° Overtaking Left-to-Right	SCENARIO S51	1.5	BEHIND	2.5	12000	16000	16000	130	200			Required
	SCENARIO S52	1.0	BEHIND	2.5	12000	16000	16000	130	200			
	SCENARIO S53	0.5	BEHIND	2.5	12000	16000	16000	130	200			Required
	SCENARIO S54	0.0	MERGE	2.5	12000	16000	16000	130	200		Required	
	SCENARIO S55	0.5	FRONT	2.5	12000	16000	16000	130	200		Required	Required
	SCENARIO S56	1.0	FRONT	2.5	12000	16000	16000	130	200			
	SCENARIO S57	1.5	FRONT	2.5	12000	16000	16000	130	200			Required
20° Crossing Right-to-Left	SCENARIO S61	1.0	FRONT	1.8	12000	16000	16000	150	200			
	SCENARIO S62	1.5	FRONT	1.8	12000	16000	16000	150	200			
20° Crossing Left-to-Right	SCENARIO S71	1.0	FRONT	1.8	12000	16000	16000	150	200			
	SCENARIO S72	1.5	FRONT	1.8	12000	16000	16000	150	200			Required

Self-Separation Test Day: 18-Dec-2014

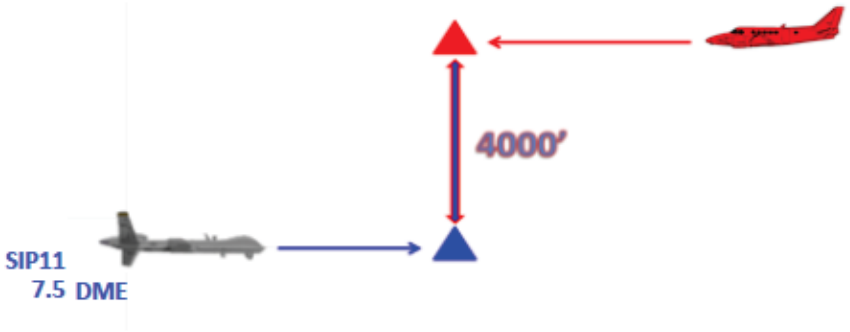
SCENARIO S12

Ikhana Card#



1. Load Lost Link Mission: 4
2. Set CONFIGURATION 2 STM: HON, TRM: VERT/COOP Display: Stratway+
3. Set MANEUVER: OFF
4. Sensors: ADS-B ON, Radar ON, TCAS TA Only ON
5. TC announces COMEX time.
6. Establish routing to arrive at IP at COMEX.
7. Cross IP at COMEX, "NASA 870, IP Inbound + altitude".
8. Announce intentions upon receiving an alert.
9. TC calls "terminate" when "Clear of Conflict".
10. TC calls next Card <Number>.

ABORT PROCEDURE
Continue Level at
12000
Through CPA



COMEX TIME:			IP TIME ADJUST:			0m + 00s
PT	LATITUDE	LONGITUDE	DME / ALT	G/S	MC	TIME HACK
SIP11	N34° 58.50'	N117° 35.00'	7.5	150	78°	IP ARRIVAL
	N34° 58' 30.0'	W117° 35' 00.0"	12000			
CP4	N34° 58.50'	N117° 25.87'	0.0	150	78°	CPA ARRIVAL
	N34° 58' 30.0'	W117° 25' 52.2"	12000			

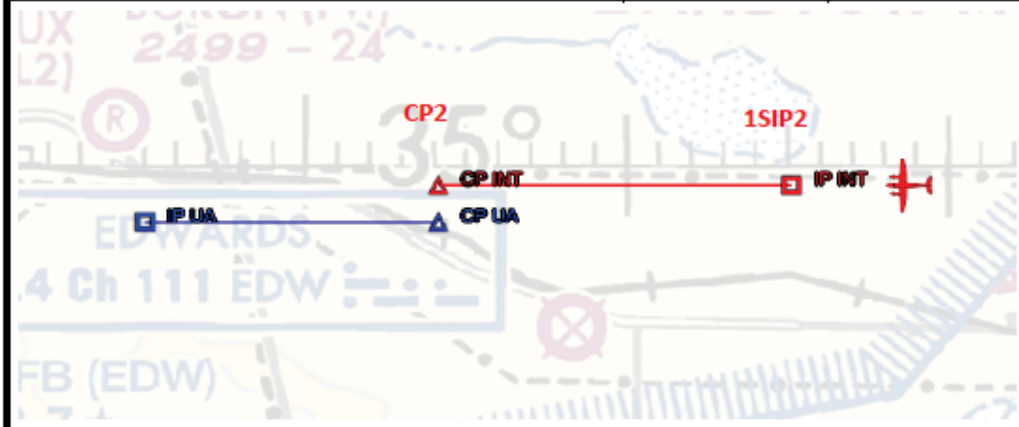
Version 6.0

Figure 5. Self-Separation Example Ikhana Test Card.

Self-Separation Test Day: 18-Dec-2014

SCENARIO S12

Intruder | Card#



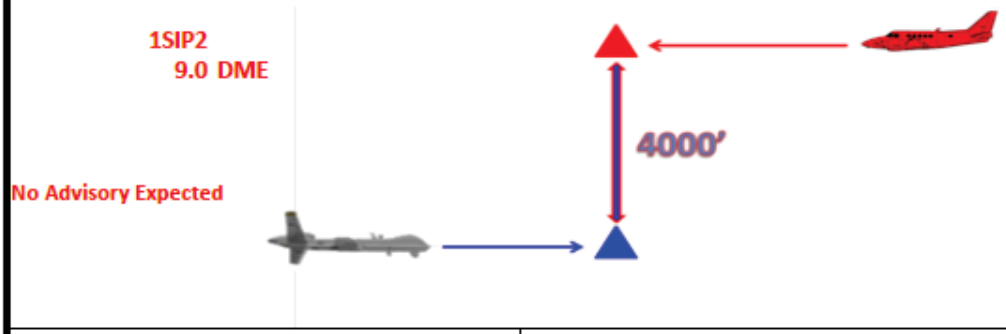
1. TC announces COMEX time.
2. Establish routing to arrive at IP at COMEX.
3. Cross IP at COMEX "<Callsign>, IP Inbound + altitude".
4. Announce advisories (if any).
5. TC calls "terminate" when "Clear of Conflict".
6. TC calls next Card <Number>.

ABORT PROCEDURE

Continue Level at

16000

Through CPA



COMEX TIME: | IP TIME ADJUST: 0m+0s

PT	LATITUDE	LONGITUDE	DME / ALT	G/S	MC	TIME HACK
1SIP2	N34° 59.50'	W117° 14.90'	9.0	180	258°	IP ARRIVAL
	N34° 59' 30.0'	W117° 14' 54.0"	16000			
CP2	N34° 59.50'	W117° 25.87'	0.0	180	258°	CPA ARRIVAL
	N34° 59' 30.0'	W117° 25' 52.2"	16000			

Version 6.0

Figure 6. Self-Separation Example Intruder Test Card.

7 Flight Summary

The following is a high level summary of each flight day.

The team performed one practice run mission on 11/14/14 where both intruder aircraft were planned to perform practice runs against the ownship (Ikhana). Scenarios X51, X52, X53, and X16 were practiced.

Mission Notes: Ikhana cancelled due to excessive surface winds (out of limits); however, the intruders did fly and practiced test runs. X51 ended in reset due to timing. X52 approximately -8 sec at CPA. X16 was Rolex due to out of position entry. X16 repeat was +3 sec at CPA. X52 (actual) was +7 sec at CPA. X53 was -2 sec at CPA. Winds were a factor during runs (~20-30 kt aloft) which impacted timing and course adherence. Overall the test runs enabled the intruders to practice the scenario timing and course.

7.1 November 17, 2014

Flight Number	1
Objective	Collision Avoidance
Flight Duration	4.5 hours
Intruder Type	Manned
Scenarios	X51, X52, X53, X54, X55, X12, X13, X14, X15, X16, X17, X18, X19, X29, X22, X23, X24, X25
Notes	[Run notes in respective order as listed, comments are objective and subjective as determined by TD; COMEX noted in local time] Cal run accomplished prior to test. HW C90 not available due to pilot medical issue. X51, 0705L, good run, neg RA; X52, 0715L, good run, RA; X53, 0728L, okay run, RA; X54, 0740L, okay run; X55, 0752L, okay run, RA; X12, 0804L, okay run, intruder -30 sec at CPA, neg RA; X13, 0814L, good run, neg RA; X14, 0824L, good run, +5 sec at CPA, neg RA; X15, 0834L, good run, +2 at CPA, neg RA; X16, 0845L, okay run, +10 at CPA; X17, 0855L, okay run, +10 at CPA, RA; X18, 0905L, okay run, +10 at CPA, RA; X19, 0915L, good run, on time, RA; X29, 0925L, good run, on time, RA; X22, 0935L, good run, on time, RA (1st auto vertical maneuver!); X23, 0945L, good run, on time, RA; X24, 0955L, good run, on time, RA; X25, 1005L, okay run, +7 at CPA, RA; RTB. Debrief Notes: N39 not allowed to enter R2515 by Joshua initially. TD called Joshua to negotiate entry which corrected the issue. VIDs in excess of 2 NM.

7.2 November 18, 2014

Flight Number	2
Objective	Collision Avoidance

Flight Duration	5.2 hours
Intruder Type	Manned
Scenarios	X51-aborted, X52, X51, X54, X12, Bonus RA, X13-Aborted, X13, X14, X19, X29, X22, Bonus RA, X23, X53, X55, X18, X26, X27, Bonus RA, X28, X24, X25
Notes	[Run notes in respective order as listed, comments are objective and subjective as determined by TD; RA based on ownship system; COMEX noted in local time] Cal run accomplished prior to test. X51, 0652L, N3GC nav error (wrong CPA), abort; X52, 0701L, good run, RA; X51 (repeat), 0711L, good run, auto RA; X53, 0721L, good run, RA; X12, 0731L, okay run, RA; X13, 0741L, abort due to timing; X13 (repeat), 0746L, good run, RA; X14, 0807L, neg RA, VID 1.5 NM; X19, 0818L, okay run, RA; X29, 0828L, 1 NM VID, poor run, N3GC ahead of 870, early RA; X22, 0838L, good run, on time, RA; X23, 0848L, good run,+5 sec at CPA, RA; delay by SPORT 870 hold in 4 corners; N3GC RTB (fuel); NASA 865 (T-34C) intruder; X53, 0939L,okay run, +16 sec at CPA, RA; X55, 0949L, good run, on time, RA; X18, 0959L, good run, -5 sec at CPA, RA; X19, poor run, +30 sec at CPA; X26, 1009L, good run, RA; X27, 1019L, good run, +5 sec at CPA, RA; X28, 1029L, okay run, descend RA (vice expected climb) 865 chose to maneuver high based on VID; X24 (add on card), 1040L, good run, +4 sec at CPA, RA; X25 (add on card), 1050L, good run, +2 at CPA, RA; RTB. Debrief Notes: N3GC modified run entry procedure to correct timing issue, altimeter correction causes TCAS to increment to next 100', PE request to rerun X28 at some point.

7.3 November 20, 2014

Flight Number	3
Objective	Collision Avoidance
Flight Duration	5.8 hours
Intruder Type	Manned
Scenarios	X31-Aborted, X31, X32, X33, X34, X35, X41, X42, X43, X44, X45, X36, X37-Aborted, X37, X38, X39, X46, X47, X48, X49, X36, X37, X38, X39, X31, X32, X33, X34, X35
Notes	[Run notes in respective order as listed, comments are objective and subjective as determined by TD; RA based on ownship system; COMEX noted in local time] Cal run accomplished prior to test. X31, 0634L, aborted run due to timing (N39); X31 (repeat), 0644L, good run, on time, ↘RA; X32, 0654L, on time ,↘RA; X33, 0704L, on time, ↘RA; X34, 0714L, on time, ↘RA; X35, 0724L, on time, ↘RA; X41, 0734L, on time, ↘RA; X42, 0741L, on time, ↘RA; X43 (intruder blunder maneuver), 0750L, on time, ↘RA; X44 (intruder blunder maneuver), 0759L, on time (0 sec), ↘RA; X45 (intruder blunder maneuver), 0809L, on time, ↘RA; X36 (intruder blunder maneuver), 0819L, N39 +5 sec at CPA, ↗RA; X37 (intruder blunder maneuver), 0833L, reset due to 870 timing; X37 (repeat) (intruder blunder maneuver), 0838L, on time (0 sec), ↗RA; X38 (intruder blunder maneuver), 0848L, on time (0 sec), ↗RA; X39 (intruder blunder maneuver), 0858L, on time, ↗RA; X46 (intruder blunder maneuver), 0908L, +5 sec at CPA,

	manual ↗ (auto ↘RA given to 870,pilot paddled off); X47 (intruder blunder maneuver), 0918L, on time, ↗RA; X48 (intruder blunder maneuver), 0928L, on time, ↗RA; X49 (intruder blunder maneuver), 0938L, on time, ↗RA; X36 (intruder blunder maneuver), 0948L, on time, ↗RA; X37 (intruder blunder maneuver), 0958L, on time (0 sec), ↗RA; X38 (intruder blunder maneuver), 1008L, on time, ↗RA; X39 (intruder blunder maneuver), 1018L, on time, ↗RA; N39 RTB at 1020L; N3GC assuming intruder role; X31 (intruder blunder maneuver), 1028L, terminated due to req alt cal needing to be accomplished; X31 (intruder blunder maneuver), 1040L, on time, ↘RA; X32 (intruder blunder maneuver), 1050L, on time (0 sec), ↘RA; players restricted to East Range and 4 Corners due to higher priority mission; X33 (intruder blunder maneuver), 1100L, on time, ↘RA; X34 (intruder blunder maneuver), 1110L, on time (0 sec), ↘RA; X35 (intruder blunder maneuver), 1120L, N3GC called out of southern boundary by SPORT, on time, ↘RA; RTB.

7.4 November 21, 2014

Flight Number	4
Objective	Collision Avoidance
Flight Duration	4.8 hours
Intruder Type	Manned
Scenarios	X41, Bonus RA, X42, Bonus RA, X43, Bonus RA, X43, X44, X45, X21, X46-Aborted, X46, X47, X48, X49, X49, X28-Aborted, X28, X38-Aborted, X38, X28-Aborted, X28, X38, X48, X46, X49, X39
Notes	[Run notes in respective order as listed, comments are objective and subjective as determined by TD; RA based on ownship system; COMEX noted in local time] Cal run accomplished prior to test. X41, 0640L, reset due to 1 NM lateral nav error (N3GC) & +40 sec timing error (870); X41 (repeat), 0645L, okay run, both +15 sec timing error, ↘RA; X42, 0655L, okay run, neg RA; X43, 0705L, okay run, HW STM problem, neg RA; X43 (repeat), 0716L,HW STM issue, +4 sec timing error, ↘RA; X44, 0726L, good run, ↘RA; X45, 0736L, ↗RA, aborted run due to expected ↘RA Ikhana pilot manually performed descent maneuver no abort call made; X21, 0746L, good run, ↘RA; X46, 0756L, scenario reset due to N3GC config issue; X46 (repeat), 0801L, good run, ↗RA; X47, 0811L, reset scenario due to N3GC timing; X47 (repeat), 0816L, neg RA; X48, 0826L, neg RA; X49, 0836L, neg RA; TC called for repeat of X49; X49 (repeat), 0846L, neg RA; TC requested 870 recycle SAAP; X28, 0856L, reset due to N3GC timing; X28 (repeat), 0901L, good run, ↗RA; X38, 0911L, reset due to N3GC timing; X38 (repeat), 0916L, good run, ↗RA; X28 (config change FAA STM), 0926L, reset due to N3GC lost GPS signal; X28 (repeat), 0932L, reset due to N3GC timing; X28 (repeat), 0936L, neg RA; X38, 0946L, neg RA (N3GC timing); X48, 0959L, good run, ↗RA; X46, 1009L, good run, ↗RA; X49, 1019L, okay run, neg RA (may be due to intruder blunder maneuvering); X39, 1029L, TC called intruder blunder maneuver, good run, ↗RA; RTB.

7.5 December 9, 2014

Flight Number	5
Objective	Collision Avoidance
Flight Duration	3.9 hours
Intruder Type	Unmanned
Scenarios	X11, X12, X13, X14, X15, X22, X22, X23-Aborted, X23, X24, X25-Aborted, X25
Notes	[Run notes in respective order as listed, comments are objective and subjective as determined by TD; RA based on ownship system; COMEX noted in local time] 870 takeoff at 0611L; Cal run 0627L; X11, 0745L, good run, ↗RA; X12, 0757L, great run, ↗RA; X13, 0807L, 870 slow, good run, ↘RA; X14, 0817L, good run, ↘RA; X15, 0827L, nice run, ↘RA; X22 (1st 300ft vert sep run, UA v UA, advisory only), 0837L, very nice run, ↘RA; X22 (repeat Auto), 0847L, perfect run, ↘RA **[this run made history as being the first-ever, non-buffered, live, UA v UA CA flight test encounter]**; X23, 0857L, rest due to timing (-13 sec IP entry); X23 (repeat), 0904L, good run, ↘RA; X24, 0914L, good run, ↘RA (noted 308 weak VHF radio on mission freq); X25, 0924L, reset due to 308 timing; X25, 0930L, good run, ↘RA; Terminated mission due to 308 VHF radio problem; FINEX 0937L; RTB. Debrief Notes: minimum of 10 minutes between runs; 308 neg RA on card 3 & 4, otherwise RAs for rest.

7.6 December 10, 2014

Flight Number	6
Objective	Collision Avoidance
Flight Duration	4.8 hours
Intruder Type	Unmanned
Scenarios	X12a-Aborted, X12a, X13a, X14a, X21, X31, X41, X32, X33, X34, X35, X42, X43, X44, X45, X32, X33-Aborted, X33-Aborted, X33, X34, X42, X44, X43
Notes	[Run notes in respective order as listed, comments are objective and subjective as determined by TD; RA based on ownship system; timing (in sec) based on ownship/intruder respectively at IP; COMEX noted in local time] 870 takeoff 0629L; Cal run 0636-0710L; X12a, 0720L, reset, 870 SAAP config (tracker OFF); X12a (repeat), 0727L, good run, timing 0/-10, ↗RA; X13a, 0737L, good run, timing -7/+4, ↗RA; X14a, 0747L, good run, timing +3/+3, neg RA; X21, 0757L, good run, timing +10/+10, ↘RA; X31, 0807L, good run, timing +10/+10, ↘RA; X41, 0817L, good run, timing +13/0, ↘RA; X32, 0827L, okay run, timing -8/-6, ↘RA; X33, 0837L, good run, timing -4/-4, ↘RA; X34, 0847L, perfect run (best of day), timing 0/0, ↘RA; X35, 0857L, okay run, timing +-5/0, ↘RA (prior to blunder maneuver); X42, 0907L, nice run, timing +2/0, ↘RA; X43, 0917L, good run, timing 0/-3, ↘RA; X44, 0927L, good run, timing -5/-2, ↘RA; X45, 0937L, good run, ↘RA; X32 (500ft vert blunder), 0947L, nice run, timing 0/+2, ↘RA; X33, 0957L, reset 308 timing (10 sec early); X33 (repeat), 1004L, reset 308 timing; X33 (repeat), 1009L, good run, timing 0/-7, ↘RA; X34, 1019L, okay run, timing +10/-17, ↘RA; TD noted at this point that aircrew fatigue might be affecting quality of timing

	performance; X42, 1029L, okay run, timing +5/-2, ↘RA; X44, 1039L, good run, timing 0/+3, ↘RA; X43, 1049L, good run, timing +2/-7, ↘RA; FINEX 1051; RTB. Debrief Notes: overall nice work for CA with 0 aborts and only 4 resets due to timing, active coordination between 2 ADS-B systems worked as expected/intended—this is a huge milestone for this system, passive coordination methodology was tested—new technique—to be (perhaps) deployed with sUAS in the future. Collision Avoidance testing complete.

7.7 December 15, 2014

Flight Number	7
Objective	Self-Separation
Flight Duration	4.8 hours
Intruder Type	Manned
Scenarios	S37c, S11, S13, S21c-Reset, S21c, S25c-Reset, S25c, S27c, S27c, S31c, S51, S53, S55, S37c, S57, S55,
Notes ☜☞	[Run notes in respective order as listed, comments are objective and subjective as determined by TC; alert based on ownship system, left ☜, right ☞; COMEX noted in local time] Primary SS Display was CPDS; all runs 4K ft vert separation; mission delayed due to Ikhana GCS issue; S37c, 0845L, 870 slow, N3GC slow left of course during run, neg alert (CPA separation approx 1 NM); S11, 0859L, good run, alert ☞; S13, 0914L, good run, alert ☞; runs reversed Ikhana west bound runs; S21c, 0923L, reset 870 fast; S21c (repeat), 0925L, good run, alert ☜; S25c, 0935L, reset; S25c (repeat), 0938L, okay run, alert ☜; S27c, 0948L, radar deselected, good run, alert ☜, terminate at 3/9 line; S27c, 0958L, nice run, timing good; S31c, 1010L, good run, terminate at 3/9 line; S51,1041L, N3GC -40 sec at IP, alert ☞; S53, 1051L, good run, alert ☞; S55, 1102L, reset N3GC 1 min late; S37c, 1118L, no data; S57, 1121L, neg alert; S55, 1132L, radar only, good run, alert ☞; RTB. Debrief Notes: Zero aborts, strict adherence to planned GS and course line are required for correct results, southerly winds aloft (25-30 kt) were a factor during test.

7.8 December 18, 2014

Flight Number	8
Objective	Self-Separation
Flight Duration	4.2 hours
Intruder Type	Manned
Scenarios	R1, S12, S13, S14, S24a-Reset, S24a-Reset, S24a, S25a, S26a, S24b, S24c, S34a, S35a, S36a, S34b, S34c, S54, S16, S72, S34b, R1
Notes	[Run notes in respective order as listed, comments are objective and subjective as determined by TC; alert based on ownship system, left ☜, right ☞; COMEX noted in local time] Primary SS Display was Stratway+; 870 takeoff 0607L; R1 (zig zag), 0645L, all sensors on, terminate 3/9 line; S12, 0657L, good run, 870 -15 sec at IP, alert ☞;

	S13, 0707L, 870 -30 at IP, alert ☞; S14, 0717L, radar only run, good timing, good run, alert ☞; S24a, 0725L, reset N3GC timing; S24a (repeat), 0736L, good run, alert ☞; S25a, 0746L, good timing, good run, alert ☜; S26a, 0755L, good timing, nice run, alert ☜; S24b, 0806L, radar only, 870 +16 sec at IP, good run, alert ☜, terminate at 3/9 line; S24c, 0815L, TCAS TA only, neg TCAS, neg alert; S34a, 0824L, alert ☞; S35a, 0833L, good timing, good run, alert ☜; S36a, 0842L, ADS-B off, radar on, TCAS TA only, N3GC -30 sec at IP, good run, neg alert; S34b, 0850L, nice timing, neg alert; S34c, 0859L, N3GC +15 sec at IP, okay run, alert ☞; S54, 0908L, N3GC -20 sec at IP, alert ☞; S55, 0916L, good timing, good run, alert ☞; S72, 0925L, radar only, alert ☞; S34b (rerun), 0939L, all sensors, good run, alert ☞; R1 (rerun), 0948L, all sensors on, zig zag pattern reduced by 50% in leg lengths, alert ☜; FINEX 0951L; RTB. Debrief Notes: Second R1 did not provide intended maneuvering requirements. In both cases the intruder did not complete a full sweep as planned.

7.9 December 19, 2014

Flight Number	9
Objective	Self-Separation
Flight Duration	4.5 hours
Intruder Type	Manned
Scenarios	S13, S15, S23b, S25b, S23c, S25c, S33b, S35b, S33c, S35c, S44, R1, S44, S22b, S26b, S32b, S36b, S33c, S23b, S35b, S37c, S72, R1
Notes	[Run notes in respective order as listed, comments are objective and subjective as determined by TC; alert in degrees (magnetic heading) based on ownship system; COMEX noted in local time] Primary SS Display was VSCS; 870 takeoff 0604L; S13, 0637L, N3GC -20 sec at IP, okay run, alert 097°; S15, 0646L, alert 057°/048°; S23b, 0657L, N3GC +15 sec at IP, alert 277°/297°/357°; S25b, 0706L, 870 +15 sec at IP, alert 287°, terminate at 3/9 line, good run; S23c, 0715L, good timing, alert 277°, terminate 3/9 line, nice run; S25c, 0724L, good timing, alert 277°/287°/297°, terminate at 3/9 line, good run; S33b, 0733L, N3GC +10 sec at IP, alert 287°, terminate at 3/9 line, good run; S35b, 0742L, good timing, alert 277°/307°, terminate at 3/9 line, nice run; S33c, 0751L, nice timing, alert 287°, nice run; S35c, 0800L, good timing, alert 227°, nice run; S44 (overtake run), 0809L, good timing, alert 237°/267°/287°/207°, good run; S22b, 0839L, good timing, alert 277°/287°/277°, good run; S26b, reset timing; 26b (repeat) 0851L, alert 277°, terminate at 3/9 line, good run; S32b, 870 & N3GC +10 sec at IP, alert 277°/267°/297°/287°, terminate at 3/9 line; S36b, 0909L, N3GC +10 sec at IP, alert 227°, good run; S33c, 0918L, N3GC +10 sec at IP, alert 267°/287°/297°, terminate at 3/9 line, good run; S23b, 0927L, 870 -15 sec at IP, N3GC -10 sec at IP, alert 277°, terminate run at 3/9 line, good run; S35b, 0936L, good timing, alert 277°, terminate run at 3/9 line, good run; N3GC RTB (Bingo); NASA 865 intruder; S37c, 0950L, CPDS display, good timing, alert 255°/230°/180°, good run (note: 865 spilled out of southern boundary of Buckhorn MOA by 2NM during post scenario maneuvering); S72, 0959L, 870 -15

	sec at IP, 865 +7 sec at IP, alert 275°, terminate run at 3/9 line, okay run; R1 (zig zag), 1008L, Stratway+ display, good timing, alert 360°, good run; FINEX 0911L, RTB. Completes initial self separation flight test. Debrief Notes: Great effort by all parties to support ACAS Xu flight test. Several 'firsts' accomplished, a total of 9 missions, 170 encounters and 50+ hours of flight test data collected.

8 Lessons Learned

The many months of planning and coordination was a key factor in the success of the ACAS-Xu/SS flight tests. Although successful, several lessons learned can be drawn and built into future similar flight testing. Those lessons learned are described below.

8.1 Airspace Coordination

Early planning and coordination with AFTC airspace manager and SPORT representatives paid dividends during actual flight test.

8.2 Zeus Display set as a requirement

Providing both the Zeus and MITLL Quicklook displays for situational awareness to the test conductor and test director was essential to ACAS Xu flight test mission success and must be a requirement for follow on self separation flight test campaigns. Early assumptions that pilots on board the intruder aircraft could self-regulate the test should the mission control room displays not been available was faulty thinking. By having the 'air picture' available to the test conductor, he/she can make real time assessments of each encounter as it unfolds and make adjustments to the test (if needed). Although both systems are considered under test, ops believes that these two displays were functioning without system delays (in real time) and provided excellent information.

8.3 Schedule

Based on Ikhana staffing and turn around rates, planning back-to-back sorties was possible but not ideal or desired. A good planning baseline is no more than three sorties per week during the 'on' Friday (non-RDO week) and two days during the RDO week. Early morning missions are preferred if testing with Ikhana since spectrum is available and R-2515 airspace is uncongested prior to 0800L.

8.4 Thorough Debriefs

Thorough debriefs should be planned and accomplished in order to discuss the mission in detail with all participants. Each test card should be reviewed and discussed in order to extract important information from aircrew and support team members.

8.5 Comm with Ikhana Mission Director via TD Net

Back channel communications with the Ikhana Mission Director played a key function with understanding aircraft status during preflight activities and during mission ops. The

test director played a key role in communicating with support team members and providing the test conductor with essential information that enhanced flight test activities.

8.6 Buffer in Schedule to accommodate other organizational priorities

On a number of occasions, test team participants, aircraft, even weather factored into schedule issue that were not fully understood (or expected) prior to actual flight test. Managers should anticipate these potential unplanned deviations and build some buffer into the schedule to accommodate these unanticipated events should they occur.

9 Acronyms

ACAS	Airborne Collision Avoidance System
ADS-B	Automatic Dependent Surveillance-Broadcast
AFRC	Armstrong Flight Research Center
AFTC	Air Force Test Center
ATAR	Air-To-Air-Radar
ATC	Air Traffic Control
C2	Command and Control
CA	Collision Avoidance
COMEX	Commence Exercise
CPA	Closest Point of Approach
CPDS	Conflict Prediction and Display System
CRM	Crew Resource Management
DCP	Dryden Centerwide Procedure
DRR	Due Regard Radar
EAFB	Edwards Air Force Base
FAA	Federal Aviation Administration
FINEX	Finish Exercise
GA-ASI	General Atomics Aeronautical Systems Inc
GCS	Ground Control Station
GPS	Global Positioning System
HUD	Heads up Display
HW	Honeywell
IP	Initial Point
IT&E	Integrated Test and Evaluation
KEDW	Edwards AFB ICAO Identifier
MIT	Massachusetts Institute of Technology
MOA	Military Operating Area
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NM	Nautical Miles

NMAC	Near-Mid-Air-Collision
NOTAM	Notice to Airmen
OJT	On the Job Training
RA	Resolution Advisory
RDO	Required Day Off
RGCS	Research Ground Control Station
RTCA	Radio Technical Commission for Aeronautics
RUMS	Remote User Monitoring System
SAA	Sense and Avoid
SPORT	Call Sign for AFFTC Radar Control Facility
SS	Self-Separation
STM	Surveillance Tracking Module
TA	Traffic Advisories
TC	Test Conductor
TCAS	Traffic Alert And Collision Avoidance System
TD	Test Director
TRM	Threat Resolution Module
UAS	Unmanned Aircraft Systems
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VSCS	Vigilant Spirit Control Station